Introduction to Flight
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Lecture 05.3
Thick Airfoils

So, let us see now we look at two basic kinds of airfoil; the thick airfoil and thin airfoil. So thick airfoil basically are airfoil which have a high thickness ratio, so when you mean high thickness ratio. First of all, what is the range of thickness that airfoils generally have? Expressed as a percentage of the chord, what is the amount of thickness that you see in airfoil? So I want someone to give me a range, minimum and maximum. What do you think? What is the minimum thickness that you see in the airfoil? No, we even have airfoil with 4 percent thickness for example, if you look at an aircraft like MiG-21, MiG-21 wing airfoil was 4 percent thick. And what is the highest value? How much is the maximum thickness that you have seen for any airfoil?

Let me give you a qualifier used on aircraft, because if you go to turbine blades you can see very thick airfoils. Typically on aircraft how much do you see maximum, perhaps 20 percent ok, we rarely see beyond 20 percent. So ranging from 4 percent to 20 percent is the thickness of the airfoils.

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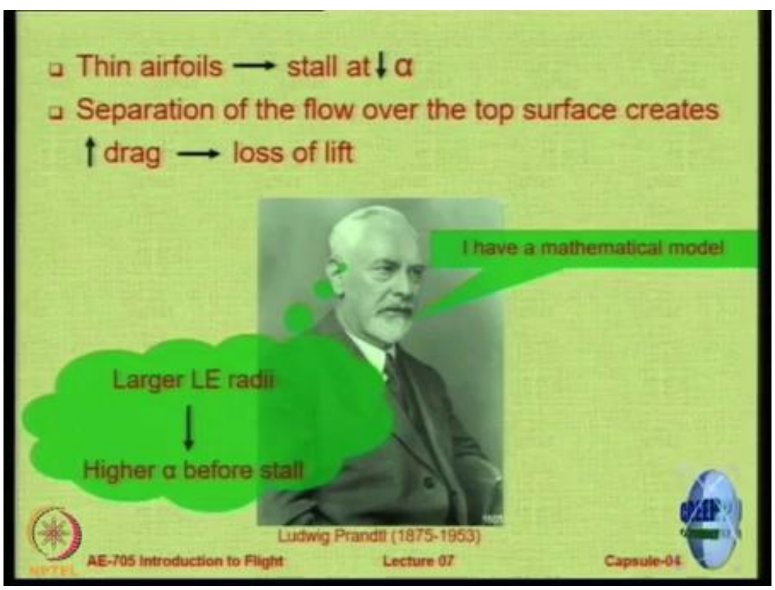

Let us have a look so, a thin airfoil it tends to stall at the lower angle of attack ok, because a thin airfoil will necessarily have very large curvature in the front so the acceleration that will take place will be very sudden over a small area. So, the separation of the flow over the top surface it will lead to lot of drag and loss of lift. So, a mathematical model was given by by Prandtl by Ludwig Prandtl and in that mathematical model it shows that the leading edge radius is very important. So larger the leading edge radius, higher is the angle at which the airfoil will stall. So, if you want to have a high angle of attack for stall, you need to go for larger leading edge radius, but a larger leading edge radius also can create problems so you have to have a mix, you cannot simply say blindly put large radius.

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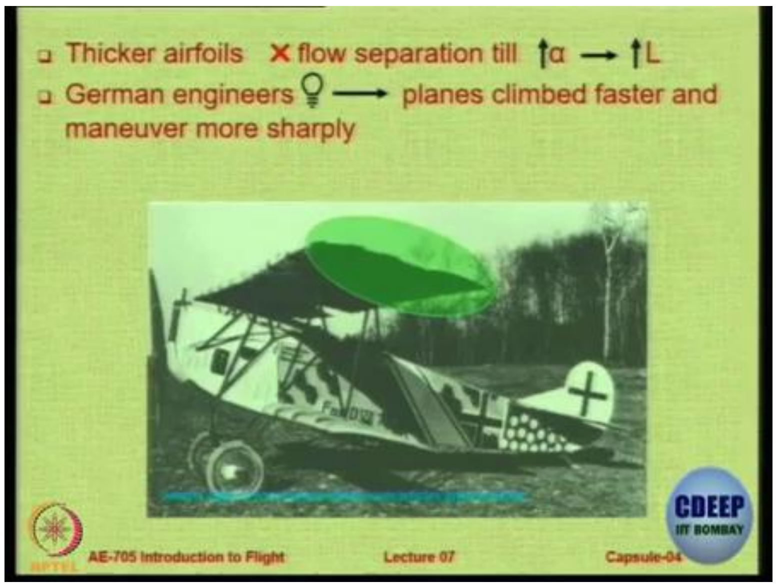

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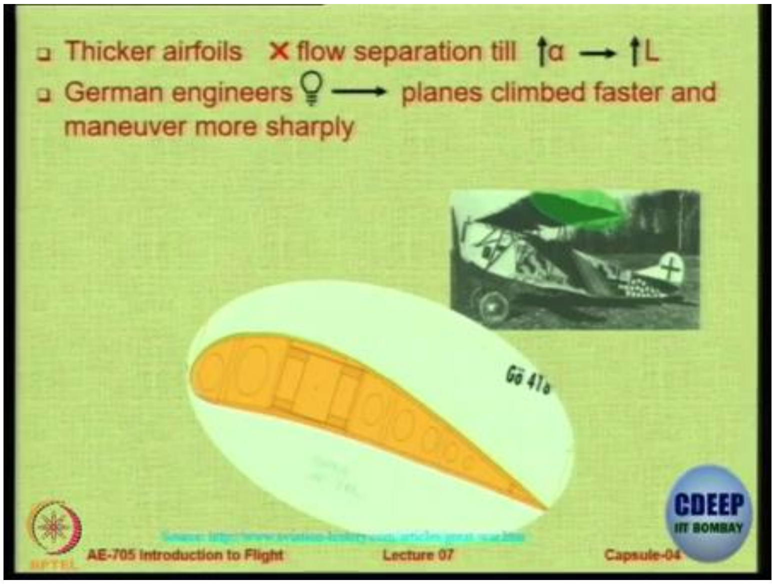

Now, thicker airfoils, they can actually avoid flow separation till high angle of attack and therefore they can continue to give you higher lift. So this particular thicker airfoils they were developed by the German Engineers during the second world war. So, till second world war or before that people were going for only thin airfoils and during the second world war when lot of research, see the second world war was a very big booster for research in aeronautics because there was a constant fight between two blocks and each of them wanted to out do the other. So, lot of design improvements, design innovations came up in the Second World War or post Second World War, one of this was the thick airfoil.

So, there is a very interesting story about how the German Engineer, how and how did allied forces realize, they captured some aircraft during the war from the Germans and when they captured the aircraft they found that this aircraft has got a very thick airfoil and still it was able to defeat the allied aircraft in combat. So, then that is how they made out, this is one example of the aircraft so you can see it is Gottingen airfoil GO 418.

I mentioned to you that a lot of research was happening in Germany in Gottingen using wind tunnels. Even today that place is very very good place to go for wind tunnel testing, they still have preserved their wind tunnels and you can see this is a thick airfoil. So one of the captured aircrafts during the Second World War was investigated by the allied forces and they wanted to find out why they are behaving much better than our aircraft and they found the reason is the thicker airfoil. So, then research on thick airfoils also began happening, plus you get more space.

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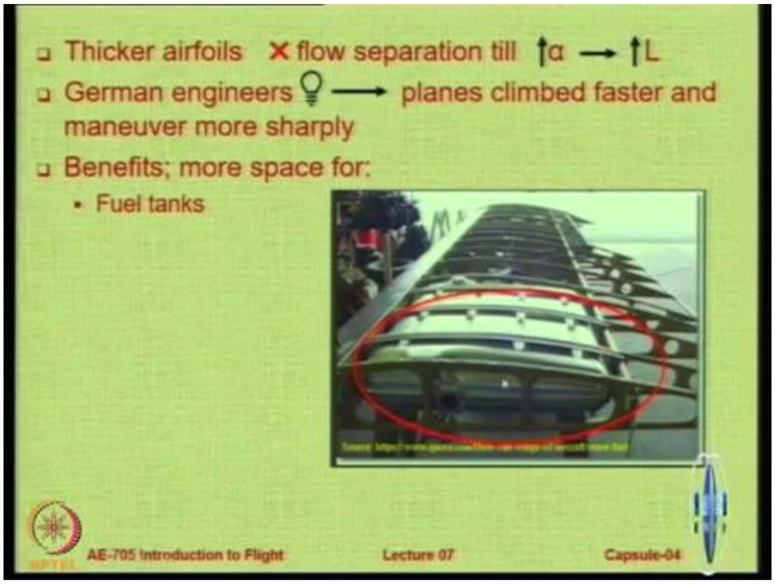

If you have thick as Ritu mentioned, if you have thickness so if you have more thickness you have more space, the wing is a place where we keep normally the fuel tanks. So thicker the wing larger the space for the fuel tank as you can see in this picture where there is a bladder fuel tank, that bladder fuel tank is enclosed between the fronts part and the rears part so this is called as the fronts part. The fronts part is typically at around quarter chord location from the leading edge and then we have a rears part which becomes the main anchor for the control surfaces for the Ailerons and Flaps that occurs at around 70 to 75 percent of the chord. So in between 25 and 75 percent of the chord in between the front and the rears part you have a cavity and then you have these longitudinal members or ribs.

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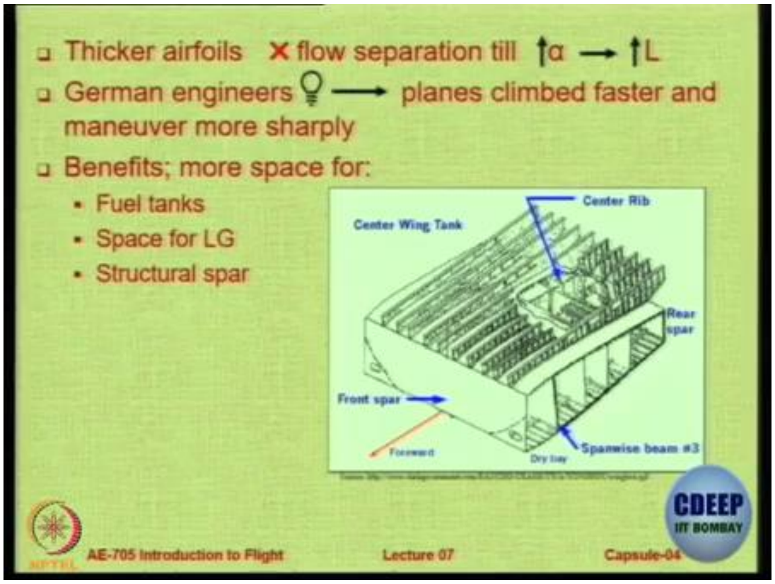

So, this whole structure forms a beautiful cavity, in that cavity in this case they have put a rubberized fuel tank but it is not necessary, you can also have red tanks like we have today in which we do not have to put rubber we can have direct metallic structure with some epoxy coatings to take care of the leakages. So, fuel tanks can be larger if you have thicker airfoils plus landing gear is required to be retracted for high speed aircraft and again you need space and the location of landing gear normally is near the center of gravity and that is where the quarter chord of the wing is. So, it is a very good place to take the landing gear inside plus it is also the place where you can put the structures spar ok. So, therefore higher T by C also helps us in getting these benefits apart from aerodynamics. So let us take a small look at some airplanes and their airfoils.

This is a video which shows a few conventional aircrafts

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so Naca 5 series 23018

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Italian Aermacchi, Naca 6 series, a popular aircraft hidden variation.

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Ok, so this is just one small image.

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Ok so now we look at certain class of airfoil which are very special. One of them is called as a Laminar flow airfoil or to qualify we can call it as a natural laminar flow NLF airfoil.

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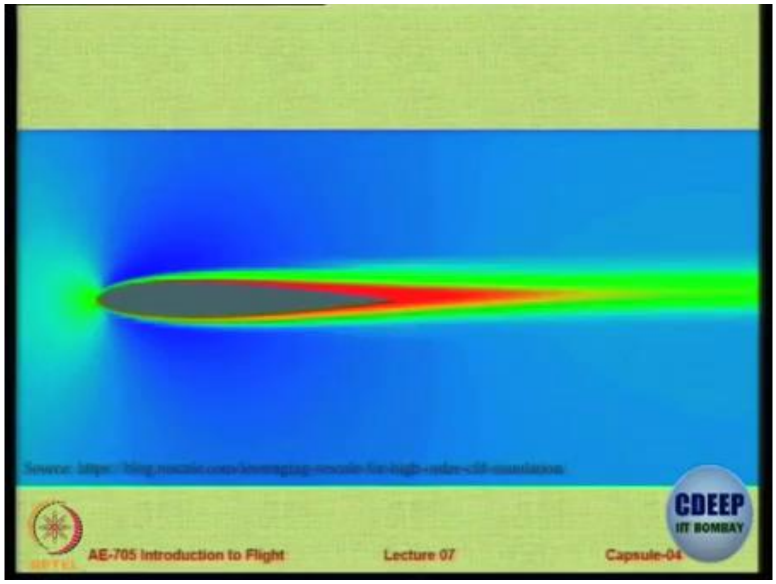

So, here is the CFD simulation and you can see that the flow is pretty much undisturbed. So, these airfoils the so called Laminar flow airfoils, they were developed in an attempt to make planes fly faster and faster.

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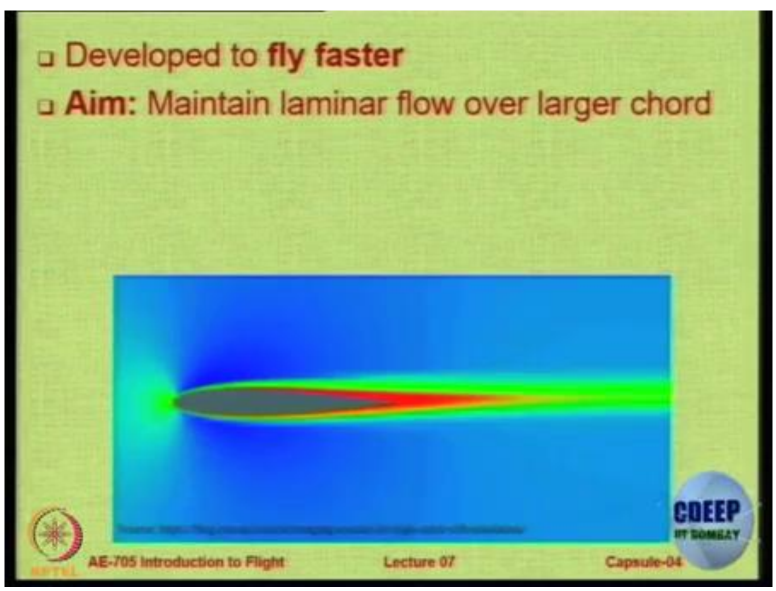

So, the aim in these airfoil was that the flow will transition to turbulent at some point, but can we push that point behind by avoiding the presence of the adverse pressure gradiant and by trying to maintain the laminar flow over a large portion, this was the aim.

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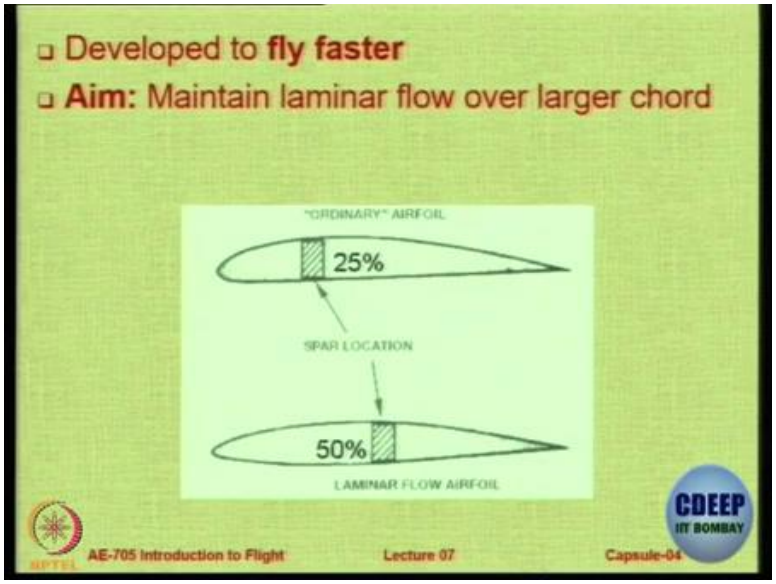

Ok, so in an ordinary airfoil the spar is located at around quarter chord and then when you have spar at that point, normally you will have rivets or some structural engagement between the skin and the spar, so in the conventional aircraft which is metallic you will find that that is the area beyond which the flow will start getting disturbed. So, you can expect transition to take place to turbulent but in the laminar flow airfoil we are shaping it essentially to push the laminar flow back so in this case you can actually have a single spar wing. You can push the spar to 50 percent of the chord and then you may not need a second spar unless there are requirements from the structure. So, there are several single spar wings and also there are several wings in which the mains spar is pushed behind so that the flow can be maintained as a laminar flow.

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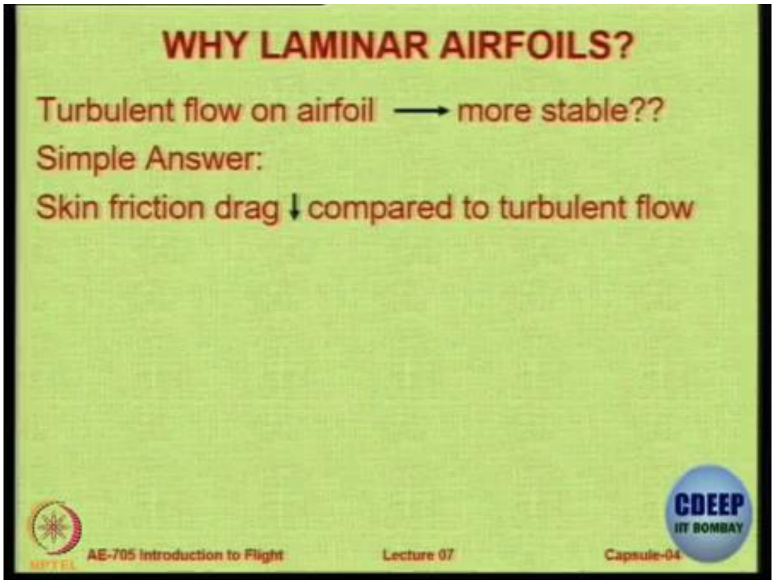

So why do we use laminar flow on airfoils? Do not we know that the turbulent flow is more stable on the airfoils? We have been seeing so many examples where we say that let us create turbulent flow intentionally by putting vortex generators, by putting these strips. We are intentionally creating the, of course the strips are for a different purpose as you all know. But my question is we all know that turbulent flow on the airfoil makes it more stable and turbulent flow also has a lesser chance of separation or I should say, it is more resistant to separation. A laminar flow separates very easily, if that is the case then why are we going for laminar flow airfoil? Can somebody answer this question? What is the advantage for going for laminar flow airfoil? Yes! Let me just get your name so your name first and then your answer.

Student: Sir, my name is Deepak.

Professor, Yes Deepak.

Student: Sir, we use laminar airfoil in order to reduce the skin friction drag.

Professor: Ok, so the motivation is to reduce the skin friction drag. So, the point is that we will study very soon about drag, there are various types of drags. One of them is Pressure Drag about which we have talked so much but we also have skin friction drag ok. And skin friction drag in laminar flow is typically one third of that in turbulent flow. So if you can maintain laminar flow, a very big if, if you can maintain laminar flow to a long large portion, it is highly beneficial because the skin friction drag is one third. But laminar flow very quickly can trip into turbulent flow just by the presence of one small projection or roughness or any small discontinuity in the flow in the surface will tip the boundary layer from the laminar to turbulent. So therefore if you design some laminar flow and then you make the engine small because it is laminar flow, drag is one third but it will not be non-laminar flow you will be always under power so it is very difficult so there are examples.

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The P-51 Mustang, a very popular aircraft during the Second World War, it was attempted to be made into an aircraft with a large amount of laminar flow. So the airfoil shaped here was a special airfoil attempting to make it as a laminar flow.

Yes ok, there is something called as a tendency for separation ok, this tendency for separation is reduced if there is energy in the flow because using that energy it can resist. So in the turbulent flow there is a larger mixing of the air within the boundary layer. In laminar flow, the flow is going in laminae, separate strips with no interaction between the two neighboring strips. But in turbulent flow there is a large amount of interaction between the various laminae that is why it is called a turbulent flow. So, because there is much larger interaction there is more energy in the flow and it is this energy in the flow which is used by the flow to, see basically when you let us say when you, why do we have separation? Because you are making the air particles because of the presence of the body at a particular angle go over the body and then follow it again. This requires energy ok.

If your flow is inherently not energetic, how do you get energy? One is kinetic energy that is because of the speed ok. So the second is because of pressure, lower altitude. At a lower altitude you have higher pressure anyway in the ambient air. So, in a laminar flow, is everything is working smoothly and if the flow is attached then there is less skin friction because only the bottommost layer is rubbing, the layers above are all rubbing the surface actually they are rubbing each other. But that too we assume that it is a frictionless kind of rubbing. In the case of turbulent flow they are actually moving in a random fashion in the boundary layer.

So, they are not moving independent of each other so the moment you provide energy to flow that energy can now be also used to overcome the obstacle. I am trying to put it in a simpler fashion because I am going to explain this in the next lectures in more detail but without using terminology without using something that will be covered later I am trying to give you a very rough example. So for example, why do we use vortex generator? What do they do? We are creating a disturbance in the flow but that disturbance is intentional. So the skin friction drag will go up but the vortices created by the vertex generator are going to energize the flow behind. And if that flow wants to separate, this energy is passed on to that flow so it adheres to the surface for a longer distance and hence the tendency for separation is reduced.

The same thing was there in the cricket ball also, okay. So, essentially what is happening is because of mixing of air in the turbulent boundary layer or in the turbulent flow in general the flow has more energy and that energy is used to overcome or resist the tendency of separation. Ok, whereas in laminar flow you have lower skin friction but you have lesser ability to withstand the separation. So a laminar flow separates very easily very quickly, a turbulent flow is difficult to separate.